DURATION 3 HOURS
No. of Students 24

Department Name & Course Number: Electronics 97.359
Course Instructor(s): Prof. John W. M. Rogers

Information and Instructions:
1. Attempt all questions.
2. Show all analysis.
3. The exam marks total 80.
4. Unless otherwise specified, use only the simplified hybrid-π model for the BJT, i.e., take \( r_e=0, \)
\( r_o=\infty, \) and \( r_\mu=\infty. \)

Useful Formulas

\[
\begin{align*}
\beta & = \frac{r_n}{g_m}, \quad r_n = (\beta+1)r_e, \quad \beta = \frac{\beta}{\beta+1}, \quad g_m = \frac{I_c}{V_T}, \quad V_T = 25mV \ @ \ 20^\circ C.
\end{align*}
\]

\[|\text{forward biased } V_{BE}| = 0.7 \text{ Volts}\]

\[
\omega_L = \omega_{L1} + \omega_{L2} + \omega_{L3} + ...
\]

\[
\frac{1}{\omega_H} = \frac{1}{\omega_{H1}} + \frac{1}{\omega_{H2}} + \frac{1}{\omega_{H3}} + ...
\]

Miller’s Theorem:

\[
Y_1 = Y \left(1 - \frac{V_2}{V_1}\right), \quad Y_2 = Y \left(1 - \frac{V_1}{V_2}\right)
\]
Question 1 (Total 12 Marks)

Answer the following questions.

2 marks  (a) For an NPN BJT draw three \( I_C \) vs. \( V_{CE} \) curves for low, medium and high \( V_{BE} \).

4 marks  (b) For the class A amplifier shown below, determine \( I_{Bias} \) so that the output swing of the amplifier is maximized. What is the efficiency of the amplifier in this case? What is the efficiency if the voltage swing is reduced by 50%?

![Figure 1](image)

2 marks  (c) A transistor is dissipating 100W. Its case has a heat sink attached. The junction to case and heat sink to air thermal resistances are 0.6\(^\circ\)C/W and 0.3\(^\circ\)C/W respectively. If the ambient temperature is 25\(^\circ\)C then what is the temperature of the transistor?

1 mark  (d) Draw a complete small signal model for the NPN BJT including \( r_x \), \( g_m \), \( C_p \), \( r_o \), \( r_b \), and either \( r_e \) or \( r_\pi \).

3 marks  (e) State one advantage and one disadvantage for each of the following amplifier configurations: (i) Common-emitter (ii) Common-base (iii) Common-collector.
**Question 2** (Total 20 Marks)

When analyzing the amplifier circuit in Figure 2, use appropriate models, to find generalized expressions (i.e. without component values unless specifically asked for).

3 marks  (a) Assume that $V_{cc} = 5V$, $I_{C1} = 1mA$, $I_{C2} = 5mA$, $R_{E1}=R_{E2}=500\Omega$, and $V_{CEsat} = 1V$. Choose $R_{C1}$ and $R_{C2}$ so that the output voltage swing is maximized.

3 marks  (b) Draw the small-signal equivalent circuit.

3 marks  (c) Find the mid-band gain $A_v$.

3 marks  (d) Find the mid-band $R_{in}$.

2 marks  (e) Find the mid band $R_{out}$ (include $r_o2$ and $r_{p2}$).

3 marks  (f) Find the low frequency poles ($\omega_L$'s) for $C_{in}$, $C_E$, and $C_{out}$.

3 marks  (g) Find the high frequency poles ($\omega_H$'s) for the circuit. You may ignore $C_{x1}$ and $C_{x2}$.

![Figure 2](image-url)
**Question 3** (Total 20 Marks)

In this question, all transistors are assumed to be matched. Perform the following analysis on the op amp circuit of Figure 3. Assume that $r_e = \infty$ for all transistors.

4 marks  (a) Assume that $V_{cc} = 15V$, and $V_{ee} = -15V$ and:
(i) Set $R_{Bias}$ so that the collector current in each of Q1 and Q2 is $500\mu A$.
(ii) Therefore determine what the collector currents in each of Q5, Q6, Q7, and Q8 are. (Ignore the output stage.)
(iii) Find the DC voltage range that can be accommodated at the input of the op-amp assuming that $V_{CEsat} = 1V$.

8 marks  (b) Ignoring the output stage determine:
(i) The differential mode input impedance $R_{DM}$
(ii) The differential mode gain $A_{DM}$ from the input to the collectors of Q6 and Q7.
(iii) The common mode gain $A_{CM}$ from the input to the collectors of Q6 and Q7 for the case where $r_o = \infty$ and when it has a finite value.
(iv) The common mode input impedance $R_{CM}$ for the case where $r_o = \infty$ and when it has a finite value.
(v) CMRR for the case where $r_o = \infty$ and when it has a finite value.

2 marks  (c) Assume that $V_{cc} = 15V$, and $V_{ee} = -15V$ and set the resistors $R_7$ and $R_8$ so that the quiescent current in each of Q9 and Q10 is $5mA$.

1 mark  (d) In one sentence explain the purpose of Q11.

2 marks  (e) If the output is shorted to $V_{CC}$, then what current is drawn through the output stage? Hint: What is the quiescent collector voltage of Q8? It will not change under this condition.

3 marks  (f) If the output is shorted to $V_{EE}$, then what current is drawn through the output stage?
**Question 4** (Total 18 Marks)

6 marks  (a) Derive the transfer function of the circuit shown in Figure 4.

![Figure 4](image)

6 marks  (b) Consider the transfer function:

\[ T(s) = \frac{v_o(s)}{v_i(s)} = \frac{LC^2 R s^2 + RC}{LC^2 R s^2 + LC s + RC} \]

Plot the amplitude response of this transfer function clearly showing the gain at \( \omega = 0 \), \( \omega = \infty \), and \( \omega = \omega_c \). Also determine Q.

4 marks  (c) Choose values for L and R so that Q = 10, and \( f_o = 1GHz \). Assume that C = 1pF.

2 marks  (d) How many poles does a 20th order chebychev low pass filter have? What is the roll off rate in the stop band?
**Question 5** (Total 10 Marks)

1 mark  (a) What is the Barkhausen Criteria?

4 marks  (b) The circuit shown in Figure 5 can be made to oscillate. The amplifier shown in the figure produces a current given by $i_o = G_M v_{fb}$ and it has an infinite input impedance. Determine the feedback gain $v_{fb}/v_o$, and the forward gain $v_o/v_{fb}$.

![Circuit Diagram](image)

**Figure 5**

4 marks  (c) Assume that an oscillator (different than above) has the following forward and feedback gains:

$$A(s) = \frac{G_M}{3}$$

$$B(s) = \frac{s}{L} \frac{\frac{2s}{RL} + \frac{1}{LC}}{s^2 + \frac{2s}{RL} + \frac{1}{LC}}$$

Determine the frequency of oscillation and determine the minimum value of $G_M$ that will cause oscillations to begin.

1 mark  (d) If $G_M$ is larger than required to start oscillations what will happen in a practical oscillator?